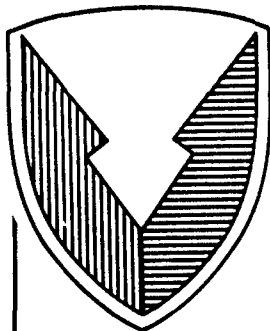2041

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# *Technical Report*

No. ___13387___

ROBOTIC VEHICLE COMMUNICATIONS INTEROPERABILITY

AUGUST 1988

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Communications interoperability (CI) amongst different robotic vehicle systems would provide many benefits to the robotics development and user communities. This report takes a first step towards CI by proposing protocols for a communications interface standard for robotic vehicle communication systems.

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NOTICES

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

# LIST OF TABLES

## 1.0.   INTRODUCTION

This technical report, prepared by the Robotics Division of the U.S. Army Tank-Automotive Command (TACOM), describes communications interoperability (CI) between different robotic vehicle systems, and also different robotic modules.  It does this by proposing protocols for a communications interface standard for robotic vehicle communication systems.

"Interoperability is critical to the Army's robotics program."[1]  Achieving CI will provide three major benefits. The first is the more effective deployment of robotic systems.  The second is the significant enhancement of testing and demonstrations.  And the third is a reduction in the cost of developing and building these systems.


## 2.0.   OBJECTIVE

The primary goal was to propose a communications interface standard, consisting of a set of protocols and a unique message format, that will lead to CI.


## 3.0.   CONCLUSIONS

This study offers the following conclusions:

- The development and adoption of a communication interface standard is a better approach to CI than the use of translators.

- Now is a good time to develop and test protocols for robotic vehicle communications because many robotic systems are still in the testbed stage.

- The use of a robotic vehicle communication subsystem suggests that:

    - The separation of the video imagery from the command and control data allows the command and control data to be transmitted on a separate, lower frequency carrier in the VHF band.  There are advantages to transmitting in this band.

---

[1]Captain Rick Lynch, Program review at TACOM, Warren, Michigan, 23 October 1987

- A digital communication system is
  superior to an analog one for the command
  and control of robotic vehicles.

● A simplified version of Synchronous Data Link
  Control (SDLC) is the most efficient data
  link layer protocol.

● A protocol for the network layer is not
  currently needed, but may be added at a later
  time.

● A transport layer protocol which adds a two-
  byte header to the message will provide the
  needed transport services.

● A block message format, developed and com-
  piled in this report, is superior to a fixed
  or variable length message format because:

    - The use of high-level commands allows
      for the ability to add additional commands
      and the capability to use the message for
      any application.  It is extremely flexible
      and will not become obsolete.

    - It reduces the bandwidth requirements of
      a communication subsystem on a complex
      robotic vehicle.

    - It allows for the use of commands which
      can be ordered by priority.

● Automating functions is a way of reducing the
  bandwidth requirements of the communication
  system.

## 4.0.  RECOMMENDATIONS

Based on the results of this investigation, the following
recommendations are submitted:

● A communication interface standard should be
  used in order to achieve CI.

● The protocols and message format proposed in
  this report should be evaluated and tested
  for application to robotic vehicle systems.
  Revisions should then be made to ensure that
  optimum protocols are available for systems
  that will be fielded.

- For a robotic vehicle communication sub-
  system:

  - Video imagery and command and control
    data should be separated, at least until
    practical image compression becomes
    available.  The command and control data
    should be transmitted in the VHF band.

  - Digital communications should be used.

- A simplified version of SDLC should be used
  as the data link layer protocol.

- A block message format should be used to
  digitally represent the control commands and
  the status information that passes between a
  control station and an RV.

- As many functions on-board the robotic
  vehicle as possible should be automated.


## 5.0.   DISCUSSION

### 5.1.   Interoperability

5.1.1.   Standard vs. Translator.   Achieving
interoperability requires one of two approaches:

- Have each entity talk in its own language, and
  have a "translator" interpret the language it
  receives.

- Develop and adopt a communications interface
  standard.

Each of these two approaches has advantages.  Using the
translator is the best way to achieve CI for a robotic
vehicle (RV) system that has already been built.  It would
be costly to redesign an existing system so that it would
meet a standard's specifications.

Adopting a standard, however, is a better approach for
systems which have not yet been built because it is more
efficient, and it will result in cost savings.

Without a standard, most developers will design their
system with no concern for communications interoperability.
Then at a later time they will need to implement a
translator.  Designing to an existing standard will save
time and money down the road.

11

A different translator would be needed for every system that is talked to. Also, it would need to be modified with the changes in functionality of every vehicle.

Using a standard cuts out one step in the communication process. With the translator, there is a "middle man" between the two entities that are communicating. Using a standard allows the two to "speak" directly to each other.

Building a communication system to standard specifications will result in several types of cost savings. The first is in the design of communication/control subsystems. Since the communication interface to be used will be described in the standard, it will not need to be designed.

The second savings will be in hardware and software costs. All communication systems adhering to the standard will have common hardware and software. Once the software is written and the hardware developed for one system, they can be used at minimal cost for other common systems.

Also, the best way to keep costs down is through competitive procurement. To achieve the cost savings of competitive procurement, and to get the highest performance possible, a high degree of compatibility between contractor's subsystems will be necessary. Adoption of a communication standard will provide this compatibility.

5.1.2. Background. TACOM contacted two offices to determine if a standard for robotic vehicle communications had already been developed: 1) The Interoperability Network Directorate of the U.S. Army Communications-Electronics Command (CECOM) at Fort Monmouth, New Jersey, which has the responsibility of making Army communication equipment compatible. 2) The Joint Tactical C3 Agency (JTC3A) of the Defense Communications Agency (DCA) in Washington, D.C., which has the responsibility of ensuring compatibility of communication equipment in the joint community (all the military services). This investigation yielded no standard.

There are three other Army programs which address inter-vehicle communications.

- Inter Vehicle Intercommunication System (IVIS) deals with digitally transferring information that is now transferred by voice. It is an Armor School concept for communicating at the battalion level and below. It is being proposed for M1A1 Block II.

- Combat Vehicle Command and Control (CVC2) is the next generation IVIS. It provides for

12

the networking of vehicles at the individual
vehicle, platoon, company and battalion com-
mander echelons.  CVC2 applies to M1A1, Brad-
ley, and future combat vehicles.

● Battlefield Management System (BMS) is the
networking of all assets at battalion level
and below.

These three programs are in the very early stages.  At this
point it is difficult to speculate how robotic vehicle
communication systems will be affected by these programs,
which are targeted for manned vehicles.

Most likely there will be commonality between the robotic
vehicle communication standard and these other battlefield
communication techniques.  But robotic vehicle communica-
tion needs are unique in some ways and thus should be
addressed.

5.1.3.  Communications Interface Standard.  The standard
must completely describe:

● The information - its structure, format, and
meaning.

● The communication system - the hardware,
protocols, and signals used to transfer the
information.

This report will describe and use the Open Systems Interco-
nnection Reference Model (OSI-RM) as a means of discussing
the issues involved in the development of a standard inter-
face document.  Before further discussing the OSI-RM, how-
ever, it is important to clarify what needs to be communi-
cated by these subsystems, what portion of those communica-
tions will be addressed in this report, and what format
(digital or analog) the communication system should use.

5.1.4.  Communication Needs.  A robotic vehicle system
communication subsystem provides for continuous, bidirec-
tional communications between a control station and one or
more RVs.  From a control station to an RV, the subsystem
provides for the transmission of signals generated at the
control station which control the functions of the RV
(movement, weaponry, etc.).

From an RV to a control station, the subsystem provides for the
transmission of signals which allow the remote operator
located in the control station to effectively operate the
RV.  These signals depict the status of the RV and its
subsystems.  Also, video and other sensory information
captured by cameras and other sensors aboard the RV are

needed.

5.1.5. Communication Portion Addressed. Robotic vehicle systems need to maintain continuous communications to avoid a control station losing control of its RVs. The ability to do so is hindered due to spectrum jamming, natural electromagnetic interference (EMI), signal attenuation, and foliage and terrain blocking the line of sight (LOS) path between the two communicating vehicles.

The communicating medium can be either hardwired (fiber optic cable, coaxial cable) or softwired (radio communications). For radio communications, there are specific advantages to transmitting at lower frequencies (VHF or UHF) as opposed to higher frequencies. See Table 5-1 for a designation of the frequencies.

These advantages include:

- The ability to penetrate foliage and other obstructions increases as frequency decreases. (See Figure 5-1)

- As frequency decreases, signal attenuation decreases.

- Simple antennas can be used instead of complex arrays.

An obstacle to using the lower frequency bands is the lack of available frequency bandwidth. Using current technology, about 6 MHz of bandwidth are required for a single FM-modulated video channel. For an RV with four video channels, bandwidth needed would be a minimum of 36 MHz.

Currently, there are no VHF or UHF bands allocated for an application requiring so much bandwidth. The existing bands are extremely congested with both military and commercial users, and it is unlikely that any bands will become available. Therefore the video imagery will need to be transmitted in the higher frequency ranges, at least until practical image compression techniques become available. Once practical compression techniques become available, it will be possible to transmit video in a VHF or UHF band.

The command and control information requires far less bandwidth than uncompressed video. The exact bandwidth required is yet to be determined, but it is in the range of 5-100 kHz. This is narrow enough to be placed in a VHF or UHF band. Therefore, it is advantageous to separate the video information from the command and control information, transmitting the video channels in the microwave band or

**Table 5-1.  Designation of Electromagnetic Waves**

| Frequency Band | Designation |
|---|---|
| 3 - 30 kHz | Very low frequency (VLF) |
| 30 - 300 kHz | Low frequency (LF) |
| 300 - 3000 kHz | Medium frequency (MF) |
| 3 - 30 MHz | High frequency (HF) |
| 30 - 300 MHz | Very high frequency (VHF) |
| 300 - 3000 MHz | Ultrahigh frequency (UHF) |
| 3 - 30 GHz | Superhigh frequency (SHF) |
| 30 - 300 GHz | Extremely high frequency (EHF) |
| NOTE:   500 MHz - 40 GHz is also designated as the microwave band. | |
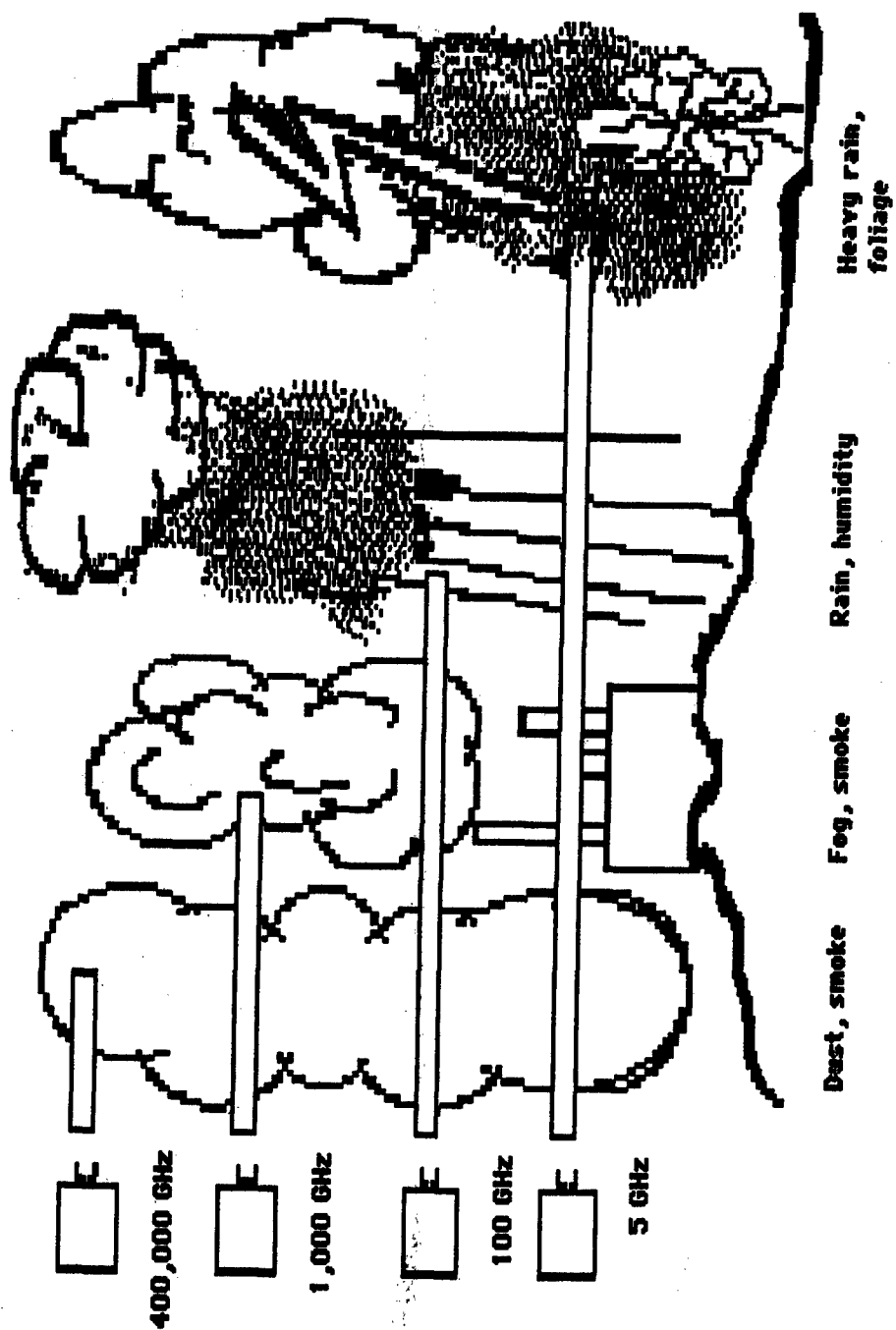
**Figure 5-1. Environmental Obscurations**

higher, and the command and control channels in the VHF or UHF band. Command of the RV can be maintained even as the video picture fades out.

The rest of this report will deal **only** with compatibility for the transmission of command and control information. It will not deal with compatibility for the transmission of video and other sensory imagery.

5.1.6. Digital Versus Analog. Command and control signals can have one of two representations, either digital or analog. Both systems have advantages.

5.1.6.1. Digital advantages.

- Good performance is possible with a signal-to-noise ratio of only 20 to 30 decibels (dB). A frequency-modulated analog system would require 30-40 dB for similar quality, and an amplitude-modulated analog signal an even higher signal-to-noise ratio.

- Works well with systems requiring the data to be relayed over multiple hops, because the digital information is regenerated at each relay. This is in contrast to an analog system, where the noise and distortions are not simply those of the weakest link, but those of the accumulation of all the relays.

- Error control techniques can be used to detect and/or correct most bit errors.

- Most encryption techniques are discrete in nature, allowing for data security.

- Transparent to the type of data. The signal could be voice, video, or computer data and any user with a compatible digital interface could receive the information. For analog systems, channels must be modeled according to the nature of the signal.

- A higher capacity per carrier frequency can be accommodated, using a time division multiple access (TDMA) technique. TDMA is a more efficient multiplexing technique than frequency division multiplexing (FDM), which is used with analog systems.

5.1.6.2. Analog advantage. Most sensors have an analog output. To use a digital system, an analog-to-digital (A/D) conversion must take place. This process increases

17

system complexity and cost. It also can introduce a quantization error.

5.1.6.3. Preferred Signal Representation. A digital system is superior to an analog system for the robotic vehicle communications application because of:

- Superior performance with the same signal-to-noise ratio

- Superior performance over multiple hops

- Available error control techniques

- Compatibility with encryption techniques

- Transparency to the type of data

- Higher capacity per carrier

The rest of this chapter will deal only with digital data communications.

5.1.7. The OSI Reference Model.

5.1.7.1. Introduction. The International Organization for Standardization (ISO) is a voluntary organization formed to make standards. TC97, one of ISO's technical committees, is concerned with information systems. TC97 developed, and in 1978 ISO introduced, the Open Systems Interconnection Reference Model (OSI-RM).

The OSI-RM is a model of a computer communications architecture. It was developed to promote compatible communications among a wide variety of digital systems. It is a framework for developing standards, and it provides the terms of reference for discussing communication system design. It has succeeded in winning general acceptance in the telecommunication industry, and therefore will be applied to the problem of robotic vehicle system's communication compatibility.

5.1.7.2. Description. The OSI-RM is not a protocol standard. Instead, it specifies seven distinct layers that define the functions involved in communicating. To implement the OSI-RM, protocols have been and are being developed and standardized at each layer.

One advantage of the OSI-RM is that all the layers are modular. This allows different groups to develop protocols at different layers with some assurance that the various layers can work together in a system. Modularity also permits the existence of sublayers, meaning multiple proto-

cols at each layer.

Each layer must communicate with the layer above and below it. They must follow rules for these interlayer interfaces.

For communicating between entities, it is imperative that all the entities have identical layers and use the same protocols.

The OSI-RM is shown in Figure 5-2. It ranges from the medium, to the Physical (lowest) Layer, and up through the Application (highest) Layer.

The bottom three layers are communication layers, concerned with the transmission of bits and bytes. These layers are hardware dominated. The top three layers are the information processing layers, adding intelligence to the bits and bytes which will be or have been transmitted. These layers are software dominated. The fourth, or middle layer, bridges the gap between these two sets of layers.

The following sections describe the medium and each layer in some detail.

- The Medium. The medium refers to the type of channel over which the signal is transmitted. Some possibilities include:

    - Air

    - Twisted pair wire

    - Coaxial cable

    - Fiber optic cable

    - Water

    - Laser

- The Physical Layer. The physical layer is the bottom, and first, layer of the OSI-RM.

    Its responsibility is to send and receive bits over the medium. It covers the physical interface between devices and the rules by which bits are sent and received. This layer is concerned with the following functions:

    - Matching the physical medium.

    - Channel encoding the data.

19

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│         7.  APPLICATION                  │
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│                                         │
│         6.  PRESENTATION                 │
│                                         │
├─────────────────────────────────────────┤
│                                         │
│         5.  SESSION                       │
│                                         │
├─────────────────────────────────────────┤
│                                         │
│         4.  TRANSPORT                     │
│                                         │
├─────────────────────────────────────────┤
│                                         │
│         3.  NETWORK                       │
│                                         │
├─────────────────────────────────────────┤
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│         2.  DATA LINK                     │
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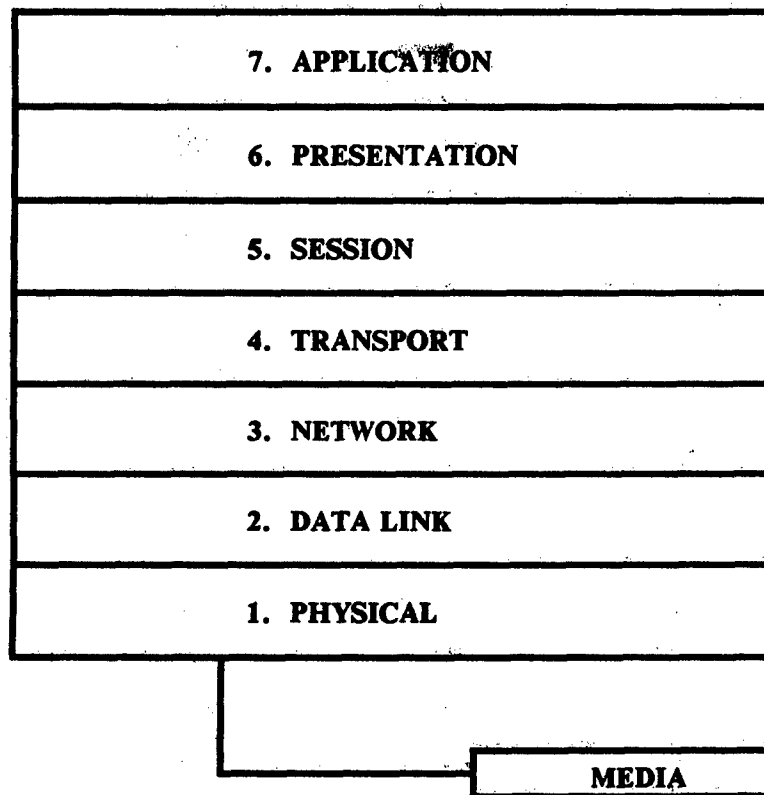
**Figure 5-2.  The Open Systems Interconnection Reference Model**

- Sequencing of events for transmitting data.

- Physically connecting the devices.

- Modulating and demodulating the signals.

● The Data Link Layer. The data link layer is the second layer of the OSI-RM. It attempts to make the physical layer reliable. It performs the following functions:

- Link management - activation, maintenance, and deactivation of the link.

- Error control - bit error detection and/or correction.

- Flow control - does not allow a fast sender to clobber a slow receiver.

- Synchronization - synchronizes the sender and the receiver that are exchanging data.

- Addressing - identifies the sender and/or receiver of the data.

To perform these functions, the bits are arranged into frames. The frames add overhead bits, which are used to perform the functions of this layer. These frames are passed down to the physical layer for transmission. The layer above the data link layer can assume error free data because the transmission errors have been corrected by this layer.

● The Network Layer. The third layer is the network layer. The network layer routes data through a network of computers/terminals. It relieves the upper layers of the need to know anything about the methodology used to establish the connection between the end entities. It also allows the lower two layers to deal only with point to point communications.

It does this by organizing the data into packets. Packets are the frames from the data link layer with additional overhead added.

● The Transport Layer. The transport layer is

the fourth, and middle, layer. It is the
bridge between the three lower communications
layers and the three higher information pro-
cessing layers. The transport layer is re-
sponsible for end-to-end (originating source
to ultimate destination) services. These
services include flow control, error control,
sequencing, survival of the connection, and
expedited delivery.

The transport layer does for an end-to-end
link (including relays and repeaters) what
the data link layer does for point-to-point
links. It performs these functions by assem-
bling the data into transport protocol data
units (TPDU). The TPDUs add overhead bits,
which are used to perform the functions of
this layer.

● The Session Layer. The fifth layer is the
session layer. The session layer provides
the mechanism for controlling the dialogue
between applications. It can do the follow-
ing:

- Establish and terminate connections.

- Provide one of three types of dialogue:
full-duplex, half-duplex, or simplex.

- Allow either abrupt or graceful discon-
nections, meaning a message can or can
not be disrupted in the midst of a
transmission, and also what to do if the
message is interrupted.

● The Presentation Layer. The presentation
layer is the sixth layer. The presentation
layer ensures that information is delivered
in a form that the receiving system can un-
derstand. Its purpose is to resolve differ-
ences in format and data representation by
defining the syntax used.

Security through encryption, message compres-
sion, and syntax conversion can also be done
at this layer.

● The Application Layer. The application layer
is the seventh, and top, layer. It serves as
a window between the application process and
the OSI communications environment. This
layer manipulates information and manages

resources to support distributed applications. To the user, this layer appears to be doing the real work.

5.1.7.3.   Application of the OSI-RM.

- The Physical Layer.  There are a variety of standard protocols for the physical layer which define all the functions for this layer.  The most popular are:

    - RS-232-C

    - RS-449/422-A/423-A

    - CCITT X.21

All three provide the necessary mechanical, electrical, functional, and procedural specifications.

RS-232-C is the oldest and most widely used of the interface standards.

The RS-449/422-A/423-A set of protocols was designed specifically to replace the RS-232-C.  It provides performance advantages over the RS-232-C in the areas of achievable transmission distances, speed characteristics, and modem control.  While the RS-232-C remains the most popular interface protocol, the RS-449/422-A/423-A set is experiencing increasing growth in usage.

X.21 is the newest and thus far the least used of the three protocols.  It provides fewer circuits (pin connections) than the other two protocols, but adds more logic. With the falling cost of logic circuitry, this can be an advantageous approach.

X.21 provides the same speed characteristics and transmission distances as the RS-449/422-A/423-A set of protocols.  It is also more flexible and potentially less costly.

Choosing the optimum physical layer protocol will involve weighing the following advantages against each other:

    - The extremely wide-spread use of the RS-232-C.

- The improved performance and growing use of the RS-449/422-A/423-A.

- The strong performance, flexibility, and potential cost savings of the X.21.

The analysis of these three protocols and the choice of an optimum one for robotic vehicle systems is outside the scope of this report.

● The Data Link Layer. To perform the functions of the data link layer, overhead bits are added to the data bits and arranged into frames. An optimum frame format is one which can effectively perform the needed functions, and do so with the minimum number of overhead bits. A minimum number of overhead bits is desired because as the overhead goes up, the amount of data that can be transmitted drops, assuming constant bandwidth.

The functions needed at the data link layer for robotic vehicle systems are:

- Synchronization

- Vehicle addressing

- Error control

Synchronization refers to the ability of the receiving entity to determine when a signal being transmitted to it starts and ends. This is usually done using some type of flag.

Vehicle addressing refers to the ability of a control station to transmit information to the RV it intends to. When there is a one-to-one control-station-to-RV ratio, as with current robotic vehicle systems, this is not necessary. Also, if each vehicle is controlled over a different channel, as with near term systems, it is unnecessary. But for far term systems, when one control station will be supervising multiple RVs, an addressing scheme will be necessary.

Error control is the ability of the receiving entity to detect and either correct or disregard data frames that have been damaged (contain erroneous bits) during transmission.

There are a variety of standard protocols

24

which perform these necessary functions.
Some of the more widely used ones are:

- High-level data link control (HDLC)

- Synchronous data link control (SDLC)

- Digital data control message protocol
  (DD CMP)

- IEEE 802.3

HDLC and SDLC are virtually identical, and
thus will be treated as one protocol.

In addition, there are many nonstandard data
link layer protocols used by communication
systems.

Using a standard protocol offers the advan-
tage of using already developed and available
communications controller hardware.  There-
fore the protocol proposed will be an exist-
ing standard.

Choosing the standard will be done by deter-
mining which protocol performs the needed
functions in a satisfactory manner with the
minimum overhead.  This can be done by exam-
ining the frame format of each protocol men-
tioned above.  The different frame formats
are shown in Figure 5-3.  Table 5-2 shows a
comparison of the different protocols.

As shown, HDLC/SDLC has the least overhead
bits per frame and also allows for a large
number of data bytes to be transmitted in
each frame.  Therefore, it is the most effi-
cient.

For robotic vehicle systems, a simplified
version of the SDLC protocol is proposed.
(See Figure 5-4.)  This protocol provides all
the needed functions.

● Network Layer.  The network layer routes data
  through a network of communicating entities.
  For current robotic vehicle system applica-
  tions, all communications are simple point to
  point (control station directly to RV).
  Therefore, no protocol is needed for this
  layer.

## HDLC/SDLC

| Flag | Address | Control | Data | Error Control | Flag |
|------|---------|---------|------|---------------|------|
| 1 byte | 1 byte | 1 byte | x bytes | 2 bytes | 1 byte |

## DD CMP

| Syn | Class | Count | Flag | Response | Sequence | Address | Error control | Data | Error control |
|-----|-------|-------|------|----------|----------|---------|---------------|------|---------------|
| 2 bytes | 1 byte | 14 bits | 9 bits | 1 byte | 1 byte | 1 byte | 2 bytes | 1 to 16,383 bytes | 2 bytes |

## IEEE 802.3

| Preamble | Starter | Destination address | Source address | Data length | Data | Error control |
|----------|---------|---------------------|----------------|-------------|------|---------------|
| 7 bytes | 1 byte | 8 bytes | 8 bytes | 2 bytes | 64 to 1518 bytes | 4 bytes |

Figure 5-3. Frame Formats

Table 5-2.  Data Link Layer Protocols

| Protocol | Synchron-ization | Vehicle Address | Error Control | Overhead Bits/frame | Data Bytes/ Frame |
|---|---|---|---|---|---|
| HDLC/ SDLC | Yes | Yes | Yes | 48 | Any number of bytes |
| DD CMP | Yes | Yes | Yes | 98 | 1-16,383 |
| IEEE 802.3 | Yes | Yes | Yes | 208 | 64-1518 |

| Flag | Address | | Data | CRC | Flag |
|------|---------|------|------|-----|------|
| | RCC | RV | | | |
| 01111110 | 3 bits | 5 bits | n bits | 16 bits | 01111110 |

Figure 5-4. Simplified SDLC Frame Format

As robotic vehicle systems become more intelligent, however, they will need to cooperate and thus should be networked together. Also, using an RV that is in the line-of-sight of the control station as a signal repeater is one way to maintain a data link with other RVs that are not in the line-of-sight of the control station.

Due to the modular nature of standards developed using the OSI-RM, a network layer protocol may be added at a later time without affecting the protocols at the other layers.

- **Transport Layer.** The transport layer makes end-to-end transmissions reliable. It does for a multihop network what the data link layer does for point-to-point communications.

Since currently we are only dealing with a direct data link between the control station and the RV, some of the transport layer services are not needed. The following services are needed:

  - Sequencing

  - Expedited delivery

  - Survival of the connection

Transport Protocol Data Units. These services are provided by assembling the data into TPDUs. For robotic vehicle systems, a TPDU consisting of a two-byte header added to the message received from the upper layers is proposed.

The first header byte is the data unit code. The second header byte is the sequence number.

TPDU Types. There are three types of TPDUs:

  - Information packet

  - Acknowledgement packet

  - Blank packet

Information Packets. An information packet carries the message from the higher layer. There are six different types of information

29

packets:

- Normal data (ND). Has the lowest priority. Will be sent last when expedited or express-type packets are waiting to be sent.

- Expedited data (ED). Has middle priority. Will be sent before normal but after express data.

- Express data (XD). Has the highest priority. Will be sent before any other packet type.

- Normal data with acknowledgement (NA). Lowest priority but requires an acknowledgement.

- Expedited data with acknowledgement (EA). Middle priority with acknowledgement required.

- Express data with acknowledgement (XA). Highest priority with acknowledgement required.

Acknowledgements Packets. An acknowledgement packet is used when the receipt of an information packet requires an acknowledgement. Only positive acknowledgements are provided. If a positive acknowledgement is not received before the transport timer expires, the software treats it as the negative acknowledgement of an information packet. A 125-ms timer is proposed.

There are three types of acknowledgements:

- Positive acknowledgement for normal data (ACK)

- Positive acknowledgement for expedited data (ECK)

- Positive acknowledgement for express data (XCK)

Blank Packets. Blank packets are used to let the other side know that the communication link is still up even though there is no information to be sent. A blank packet is sent when the transport has nothing to send

for 200 ms.  When nothing has been received
for three cycles (600 ms), an alarm message
is sent to the appropriate application soft-
ware saying that there is something wrong
with the communication link.

Data Unit Codes.  Table 5-3 has a list of the
data unit codes.

Sequence Number.  Each packet is numbered
sequentially.  Since it is a one byte number,
256 ($2_8$) TPDUs can be numbered before start-
ing over.

TPDU Lengths.  Each information packet has
the two byte header followed by a data field
of unlimited length.  An acknowledgement
packet has a total length of three bytes, the
two byte header and the sequence number of
the received information packet to be acknow-
ledged.  A blank packet consists of only the
two byte header.

- Session Layer.  The session layer can be
rather lean due to the simple point to point
communications.  One issue that can be set-
tled at this layer is the dialogue type.

There are three dialogue types:

  - Simplex: can transmit only in one direction.

  - Half-duplex: can transmit in both directions,
    but only one at a time.

  - Full-duplex:  can transmit in both directions
    simultaneously.

For maintaining effective, real-time control
of an RV, many of the control signals from
the control station and status signals from
the RV must be relayed as soon as they are
available for transmission.  This requirement
warrants the use of full-duplex communica-
tions.

Another issue that should be discussed at
this layer is the type of disconnection,
either graceful or abrupt, that should be
employed.  With a graceful disconnection, a
message that is cut off before it is com-
pletely transferred will be retransmitted as
soon as the resources to do so are available.

Table 5-3. Data Unit Codes

| TYPE | DATA UNIT | CODE |
|---|---|---|
| Information Packet | ND | 0000 0000 |
| | ED | 0000 0001 |
| | XD | 0000 0010 |
| | NA | 0000 0100 |
| | EA | 0000 0101 |
| | XA | 0000 0110 |
| Acknowledgment packet | ACK | 0000 1000 |
| | ECK | 0000 1001 |
| | XCK | 0000 1010 |
| Blank Packet | BLNK | 0001 0000 |

With an abrupt disconnection, the message that is not completely transferred is ignored.

The need for graceful disconnections arises from systems exchanging large amounts of data, such as file transfers, with no time restriction. In contrast, controlling a robotic vehicle requires many short command and status messages. Because of this, retransmission of cut off messages is not required. Therefore abrupt disconnections are proposed.

- The Presentation Layer. For robotic vehicle communication system applications, the presentation layer must provide for security and must describe the bit and byte representations of the control commands and the status information. Current and very near term robotic vehicle systems are primarily technology demonstrators, and thus do not require data security. Future fielded systems, as well as mid and far term demonstrators, will require security, and this can be provided by an encryption sub-layer of the presentation layer. Addition at a later date of this sub-layer is possible due to the modular nature of the OSI-RM.

  Description of the bit and byte representations of the control commands and the status information can be achieved by the development and implementation of a robotic vehicle message format. The development of a message format for this purpose is detailed in sections 5.2 and 5.3.

  Application Layer. The application layer takes care of functions such as file transfers, graphics, data base management, etc. Proposing protocols for this layer is out of the scope of this report.

## 5.2. Robotic Vehicle System Functions

5.2.1. Introduction. A message format describes the bit and byte representations of the control commands and status information used by a robotic vehicle system. A message format is part of the Presentation Layer of the OSI-RM, as described in the previous section.

The development of a message format can be broken down into

33

two main tasks:

> Compilation of the control functions and status information required to remotely operate a vehicle.

> A method of representing the compiled information.

This section will address the first task, that of compiling the information needed to remotely control a vehicle. The objective is to make the compilation as comprehensive as possible so that the message format can be used by any and all military robotic vehicle systems, both now and in the future, performing a wide variety of missions.

5.2.2.   Manned Military Vehicles.   Operating a vehicle remotely requires performing, at a remote location, the operations normally performed by a crew within the vehicle. To begin compiling a list of all the control commands and status information necessary to remotely control a vehicle, the operation of current manned vehicles can be studied.

5.2.2.1.   Vehicles studied.   For this study, four vehicles were chosen:

> M1A1 Abrams Main Battle Tank

> M2/M3 Bradley Fighting Vehicle

> High Mobility Multipurpose Wheeled Vehicle (HMMWV)

> ACEC Cobra

These four particular vehicles were chosen for two reasons:

- All are state-of-the-art vehicles, recognized as performance leaders in their individual fields.

- They represent a good cross section of military vehicles.
    - They represent the three general weight classes of vehicles:

        Heavy -  M1A1

        Medium -  M2/M3, Cobra

        Light -  HMMWV,
    - Three are tracked, one is wheeled (the HMMWV).

34

- Three are diesel powered, one is turbine powered (the M1A1).

- Three have mechanical transmissions, one has electric drive (the Cobra).

By studying four vehicles which are significantly different in design, a more complete list of control commands and status information which will be required on future robotic vehicle systems performing a wide variety of missions can be obtained.  Appendix A gives the results of the survey of the four vehicles.

5.2.3.  Unmanned Vehicle Systems.  Compiling a list of functions and status information needed for robotic vehicle systems can be aided by studying current robotic vehicle systems and learning from what has already been done.  This was done with systems developed or under development by the six organizations listed in Table 5-4.

These systems were studied, but the documents describing the systems will not be included in this report because of the competitive situation these companies are in.

5.2.4.  Additional Functions.  Surveying current manned and unmanned military vehicles was very helpful in compiling a control/status listing.  But future vehicles will continue to change and progress, and will have additional requirements for command and control.

To predict requirements of future systems, a series of meetings was held with personnel from TACOM's Robotics Division.  At these meetings, additional controls and status were discussed and compiled.

5.2.5.  Higher Level Control Commands.  Surveying the four manned vehicles has led to an accumulation of low-level commands required to control a vehicle.  Likewise, the Grumman, Kaman, and Sandia systems were completely teleoperated, thus accumulating more low-level vehicle control commands.

5.2.5.1  RV intelligence.  The commands required to control an RV vary greatly with the intelligence of the vehicle.  Robotic vehicle system developers are working to continually increase the intelligence of their RVs.

When RVs lack intelligence, they require many explicit low level directions on what to do and on how to do it.  As RVs gain intelligence, a smaller quantity of high level

**Table 5-4. Robotic Vehicles Studied**

- FMC Corporation

- General Dynamics Land Systems

- General Motors Delco

- Grumman Corporation

- Kaman Sciences Corporation

- Sandia National Laboratories

commands can be substituted for the many low level commands.

5.2.5.2. Autonomy. An increase in onboard RV intelligence means the vehicle has become more autonomous. An RV with increased autonomy is desired for two reasons:

1. The RV to control stations data link has a decreased bandwidth requirement.

2. Workload of RV operator is decreased.

- Decreased Bandwidth Requirement. Inter-vehicle communications on the battlefield are hindered by enemy electromagnetic warfare, as well as by natural obstacles (hills, trees, foliage) and natural electromagnetic interference. The greater the amount of information needed to be transmitted, the greater the bandwidth requirement of the communication system, and the more difficult it is to successfully transfer the data.

    Conversely, the less information that must be transmitted, the smaller the bandwidth requirement of the communication system, and the capability to successfully transfer the data is improved. Decreasing the number of commands needed by an RV lessens the amount of information that must be transmitted.

- Decreased Operator Workload. As an RV's autonomy increases, the number of moment-to-moment commands generated by the operator to command the vehicle is decreased, thus decreasing the operator workload. If the workload is sufficiently decreased, the operator can perform other duties while at the same time maintaining control of the RV. Other duties may include controlling additional RVs. This increases the productivity of the operator, and thus increases force effectiveness.

5.2.5.3. Examples. To further describe high-level commands, two examples, using vehicle speed and weapon usage, will be given.

- Vehicle Speed. At the lowest level, the speed of a vehicle is controlled by adjusting the engine throttle. This requires the operator to constantly change the throttle depending upon the vehicle, road and weather

conditions.

A higher level command would set the vehicle
speed. It would then be the job of the RV,
independent of the human operator, to gener-
ate the moment-to-moment throttle commands
needed to maintain the desired speed. A
cruise control device, common on commercial
automobiles, could be mounted on an RV and
could carry out this higher level command.

Another high-level command might be to tell
the RV to go from point A to point B in the
shortest time possible. Now the RV would
attempt to maintain the highest speed pos-
sible while taking into account the terrain
and weather conditions and the engine and
vehicle limitations.

- Weapon Usage. At the lowest level, the oper-
ator would detect a target. He would then
send commands to position the weapon and to
fire it.

  At a higher level, the operator might still
  need to detect the target. He could then send
  a command, "Lock on target." When the weapon
  had autonomously locked on the target, the
  operator could send a command to fire.

  At the highest level, the operator could give
  the single command, "Engage enemy." The RV
  would then autonomously detect a target, posi-
  tion the weapon, and fire at the target.

5.2.5.4. Need for high-level commands. The principal
argument used against the adoption of standards is that
they tend to freeze technology, and become obsolete. It is
imperative that the developer of a standard take into
account future requirements so that the standard would not
become obsolete.

With RVs, the trend is for increased onboard intelligence.
Therefore, the standard message format developed in this
document must include high-level control commands, as well
as have the flexibility to add additional high-level
commands as they are needed.

5.2.6. Automated Functions. Increasing the autonomy of
RVs (using high-level commands) is one method by which to
reduce the bandwidth requirements of robotic vehicle
communication systems. Another method is to automate as
many functions as possible.

An automated function is one which normally must be performed by a human operator but can be done autonomously. It differs from a high-level command in that it needs no operator supervision at all.

There are many functions that have the potential to be automated. An example of one is the operation of a vehicle's bilge pumps.

Bilge pumps are turned on by a vehicle's crewmember when water has entered the hull. The function of turning on the bilge pump could be automated by putting water sensors in appropriate locations. Upon sensing a predetermined amount of water, the bilge pumps would automatically turn on. Also, the pumps would automatically turn off when the water has been flushed out. Automating the operation of the bilge pumps would give the RV operator one fewer function to control and would delete the need to send a control command.

Some of the other functions that are candidates for automation include:

Interior temperature

Suspension height

Fuel tank selector

Fire extinguishing system

Camera lens focus

5.2.7. Complete Control/Status Listing. Appendix B contains the results of this section.

5.3. Representation of the Compiled Information
The control commands and the status information compiled in the previous section can be digitally represented by a message format. Three different types of message formats are considered:

Fixed-length message format

Variable-length message format

Block message format

5.3.1. Description of the message formats. The three types of message formats are described below.

5.3.1.1. Fixed-length message format. A fixed-length

message format is a stream of parameters in a predetermined sequence. (See Figure 5-5.(a)) The location of the parameters within the stream dictates the function being controlled and the status information being transferred.

The RV knows what to do with each parameter because of its location in the sequence. No function identification is necessary in this type of message format.

5.3.1.2. Variable-length message format. A variable-length message format, like a fixed-length message format, is also a stream of parameters in a predetermined sequence. With a variable-length format, however, a parameter is only sent when it is needed.

Whether or not a parameter is needed is depicted by a "parameter needed (PN)" bit. (See Figure 5-5(b)) When the PN bit is set (has a value of one), a parameter is needed and will immediately follow. When the PN bit is not set (has a value of zero), a parameter is not needed and thus will not follow. The following bit will instead be another PN bit.

5.3.1.3. Block message format. With a block message format, each parameter is individually identified. (See Figure 5-5(c)) Parameters are not part of a data packet with a predetermined parameter sequence, as with the fixed-and-variable length message formats.

Not being part of a sequence, different parameters can be sent at different frequencies. For example, an RV being remotely driven out to a sentry post may require hundreds of steering commands, but no weapon control commands.

Because the parameters are not transmitted in a predetermined sequence, they must each be identified. This is done with a series of labels.

The message length is variable. When little or no activity is required, the message length will approach zero bytes. An RV performing a variety of functions in a complex environment will have a long message length.

The parameter labels also vary in length. Some messages require more bits than others to be accurately identified.

5.3.2. Analysis of the message formats.

5.3.2.1. Fixed-length message format. The fixed-length message format offers two advantages. The first is that no bits are needed to identify to what application the transmitted parameters apply. All the bits of data are parameters. This makes for an efficient use of the data

40

| Steer | Brake | Throttle | Camera | Gear |
|-------|-------|----------|--------|------|

**(a) Fixed Length Format**

| PN | Steer | PN | Brake | PN | Throttle | PN | Gear |
|----|-------|----|-------|----|----------|----|----- |

**(b) Variable Length Format**

| Function Identifier | Control Parameter |
|---------------------|-------------------|

**(c) Block Format**

Figure 5-5. Candidate Message Formats

41

link.

The second advantage is the simplicity with which an RV and
a control station can handle the received message. Routing
the parameters to the proper location is easily done since
the parameter applications are predetermined.

There are three disadvantages to using a fixed-length
message format. The first is that the frequency with which
a parameter is sent cannot be varied. A parameter is sent
once in every message. Even though a parameter may not be
needed, it is still transmitted. This leads to the
transmission of unneeded parameters.

The second disadvantage is that there is no way to order
the parameters by priority . Since the parameters must be
sent in their predetermined sequence, there is no means to
send a more important parameter before a less important
one.

The third disadvantage is the lack of flexibility that this
type of message format offers. Different types of robotic
vehicles require different control commands and status
information depending upon their configuration and the
mission they are performing. A message format must be able
to accommodate different requirements if it is to become a
standard. The fixed-length message format does not offer
this flexibility since it would need to be altered for each
different application.

5.3.2.2. Variable-length message format. The advantages
and disadvantages of the fixed-length message format also
apply to the variable-length message format, with two
differences. The first is that the variable-length message
format is more data rate efficient than the fixed-length
format. This is because parameters are not transmitted if
they are not needed.

The second difference is that there is an increase in the
processing required of the receiving entity when using the
variable-length format. The receiving entity must
determine if it should or should not route the parameters
to certain applications, depending on the value of the
"parameter needed" bit.

5.3.3.3. Block message format. There are three advantages
to using a block format. The first advantage is the
flexibility of this format. Functions can be identified
for each vehicle and mission module, but only those
applicable to a particular system need to be used.

As requirements for robotic vehicle systems develop and
evolve, new messages can be added and obsolete ones

42

deleted. This will keep the message format from becoming obsolete.

The second advantage is that the parameters can be ordered by priority. This is possible since they are not arranged in a predetermined sequence.

The third advantage is that messages are only sent when needed, decreasing data rate requirements.

There are two disadvantages to using a block message format. The first is that each parameter needs to be identified. This can be done with a label two bytes in length.

The second disadvantage is the burden put on the receiving entity. Upon the receipt of data, it must be processed to determine what application the parameter is for.

5.3.4. Comparison. Table 5-5 summarizes the advantages and disadvantages of the three message formats presented in this chapter.

As shown, the bandwidth required for each message format varies with the complexity of the message. For a robotic vehicle system requiring few commands, the variable-and fixed-length message formats can operate over links using slower data rates. The block format requires faster rates.

For a more complex robotic vehicle system requiring many different commands, the block format can use the link with the slowest data rate because it only sends messages when they are needed.

The block format is flexible and allows commands to be ordered by priority. Flexibility is extremely important for a message format that is to be part of an interface standard. Without flexibility, the standard will not likely be adopted.

Neither the fixed-nor-variable length message formats offer flexibility or the ability to order commands by priority.

A communication system using a functional block format requires the most processing by the receiving entity. The fixed-length message format requires the least processing, and the variable-length format requires an intermediate amount.

The increased amount of processing time and resources required when using a functional block format is a penalty to adopting this format. But this penalty is negligible

43

**Table 5-5. Message Format Comparison**

| Message Format | Flexible | Bandwidth required | Processing required | Prioritized commands |
|---|---|---|---|---|
| Fixed Length | No | Varies with message complexity | Least | No |
| Variable Length | No | Varies with message complexity | Medium | No |
| Functional Block | Yes | Varies with message complexity | Most | Yes |

because of the increasing speed and decreasing cost of computer equipment.

These facts, plus the flexibility and the ability to order the messages by priority, make the block format the best message format for a robotic vehicle communications interface standard.

5.3.5. Proposed Message Format. There are many different possible structures that a block message format can take. The format proposed for robotic vehicles is shown in Figure 5-6. Appendices C and D define the digital coding for the messages.

5.3.5.1. Field descriptions. The message length field is one byte in length and describes the length (number of bytes) of the message, including the length byte itself. The source address field is also one byte in length and it tells where the message originated.

The message field can be broken down into multiple commands. Each command consists of:

- A length field one byte in length which describes the length (number of bytes) of the command, including the length byte itself.

- A block field one byte in length. This field is the first part of the command/status identifier. Its one byte length makes it possible to identify 256 ($2^8$) different blocks. The blocks are the result of the control commands and the status information being classified according to their function.

- One or more function fields. Each function field consists of a one byte function identifier, which is the second part of the command/status identifier. The one byte length makes it possible to identify 256 functions per block. Where necessary, a parameter one or more bytes in length follows. A parameter is the actual control or status value.

5.3.5.2. Parameter types. There are three types of parameters which can be used:

Numeric (N)

Select (S)

Proportional intensity (PI)

The type of parameter associated with each block is shown in Appendices D and E.

45
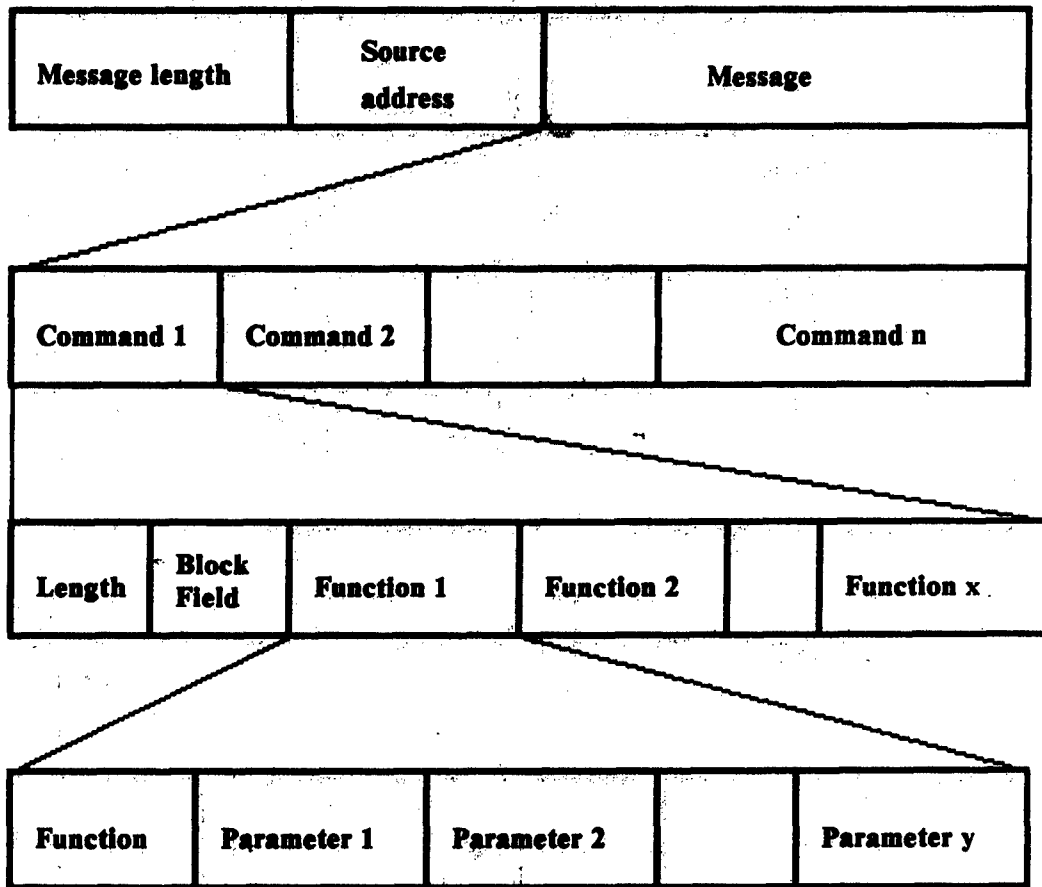
**Figure 5-6.  Command/Status Message Format**

5.3.5.3. Parameter representations. Numeric parameters are represented with binary encoding. For example, decimal 71 is represented by 0100 0111. This is hexadecimal 47.

Select parameters are used when we need to choose one or more options from a group of choices.

Proportional intensity parameters are used to represent three types of commands/status:

Off, incrementally increasing to full on.

Down, incrementally rising to full up.

Straight ahead, incrementally changing to full left or full right.

- Off to on is represented by a one-byte parameter. Hexadecimal 00 (binary 0000 0000) represents off. Hexadecimal FF (binary 1111 1111) represents full on. All values inbetween represent proportional positions.

- Down to up is represented by a one-byte parameter. Hexadecimal 00 represents full down. Hexadecimal FF represents full up. All values inbetween represent proportional positions.

- Left to right is represented by a one-byte signed parameter. Hexadecimal 7F is full left. Hexadecimal 00 is straight ahead. Hexadecimal FF is full right. All values inbetween represent proportional positions.

5.3.5.4. Message generation. Messages are generated using the following steps:

Determine the block field codes from Appendices D and E.

Get the function field code from Appendices D and E.

Append the required parameters.

Determine the message length and the command lengths.

Enter numeric values into the message format.

5.3.5.5. Examples. Three examples are given which

illustrate using Appendices D and E and the message format to generate coded messages which represent control commands and status information.

Example 1. An operator initiates the following commands:

- Turn vehicle full right

- Engine at half throttle

- Turn on headlights

- Turn on the power to the FLIR

The following chart is used to put the commands into the required message format:

| Command Number | Message | Block Field | Function Field | Parameter | Length |
|---|---|---|---|---|---|
| 1 | Vehicle full right | 03 | 01 | FF | 04 |
| 2 | Engine half throttle | 01 | 03 | 40 | 04 |
| 3 | Turn on headlights | 0E | 01 | | 03 |
| 4 | Power to the FLIR | 18 | 01 | | 03 |

The resulting message, in hexadecimal values, is:

10 03 04 03 01 FF 04 01 03 40 03 0E 01 03 18 01

NOTE: Source address has arbitrarily been chosen to be 03. Also, the above codes would be put in the SDLC format for transmission over the data link.

Example 2. An operator initiates the following commands:

- Engine at zero throttle

- Turn heater on

- Turn air conditioner off

- Turn on bilge pump

- Stop transmitting video from the left and right peripheral cameras

- Begin transmitting images from the reconnaissance camera and the FLIR

The following chart is used to put the commands into the required message format:

| Command Number | Message | Block Field | Function Field | Parameter | Length |
|---|---|---|---|---|---|
| 1 | Zero throttle | 01 | 03 | 00 | 04 |
| 2 | Heater on | 0D | 03 | | ~~04~~ *05* |
| | AC off | | 06 | | |
| | Bilge pump on | | 09 | | |
| 3 | Stop transmission of right peripheral camera imagery | 10 | 08 | | ~~08~~ *06* |
| | Stop transmission of left peripheral camera imagery | | 06 | | |
| | Transmit FLIR images | | 0F | | |
| | Transmit reconnais-- sance images | | 0B | | |

The resulting message, in hexadecimal values, is:

11 03 04 01 03 00 05 0D 03 06 09 06 10 08 06 0F 0B


Example 3. An RV's central control unit initiates the following status messages:

- Engine hot

- Fuel low

- Interior temperature 72$^{\circ}$

The following chart is used to put the commands into the required message format:

| Command Number | Message | Block Field | Function Field | Parameter | Length |
|---|---|---|---|---|---|
| 1 | Engine hot | 81 | 06 | | 03 |
| 2 | Fuel low | 8B | 02 | | 03 |
| 3 | Interior temperature | 8D | 01 | 48 | 04 |

Message:  0C 03 03 81 06 03 8B 02 04 8D 01 48

5.3.5.6.  Request for status.  A request for status is made by sending the appropriate status identifier from a command center to an RV.  For example, a request command for the RV's heading would have the block field B0 and the function identifier 01.

5.3.5.7.  Room for growth.  The proposed message format will only be effective if it does not hinder the

development of new systems and subsystems. Therefore it must be flexible and have room to grow. By using one byte to identify the message block, there are 256 possible blocks. The current compilation of messages resulting from the investigation described earlier produced 62 blocks, leaving ample room for expansion. Also, by using one byte to identify the functions in each block, there are 256 possible functions. So far, the most identified for any one block is 27.

5.3.6. Complete Message. The message format described in the previous sections will become part of the whole data packet that is transferred between entities. The whole packet also includes the transport layer protocol overhead as well as the data link layer protocol overhead.

Figure 5-7. illustrates the entire data packet including data link, transport, and presentation layer protocols overhead.

5.4. Protocol Testing

The proposed protocols and message format will be implemented in TACOM's Robotic Combat Vehicle program in fiscal years 1989 and 1990. This will allow the protocols to be tested.

Also, TACOM will make the documentation available to other robotic systems being developed so that they may evaluate the proposed protocols as well. This will lead to identification of any revisions or improvements required to make the protocols fully functional.

By evaluating and testing communication protocols now, while robotic vehicle systems are still in the testbed stage, an optimum set of protocols can be available when robotic vehicles are ready for full-scale development.

| Flag | Address | Data | CRC | Flag |
|------|---------|------|-----|------|

| Sequence Number | Data Unit Type | Data |
|-----------------|----------------|------|

| Message length | Source address | Message |
|----------------|----------------|---------|

| Command 1 | Command 2 | | Command n |
|-----------|-----------|--|-----------|

| Length | Block Field | Function 1 | Function 2 | | Function x |
|--------|-------------|------------|------------|--|------------|

| Function | Parameter 1 | Parameter 2 | | Parameter y |
|----------|-------------|-------------|--|-------------|
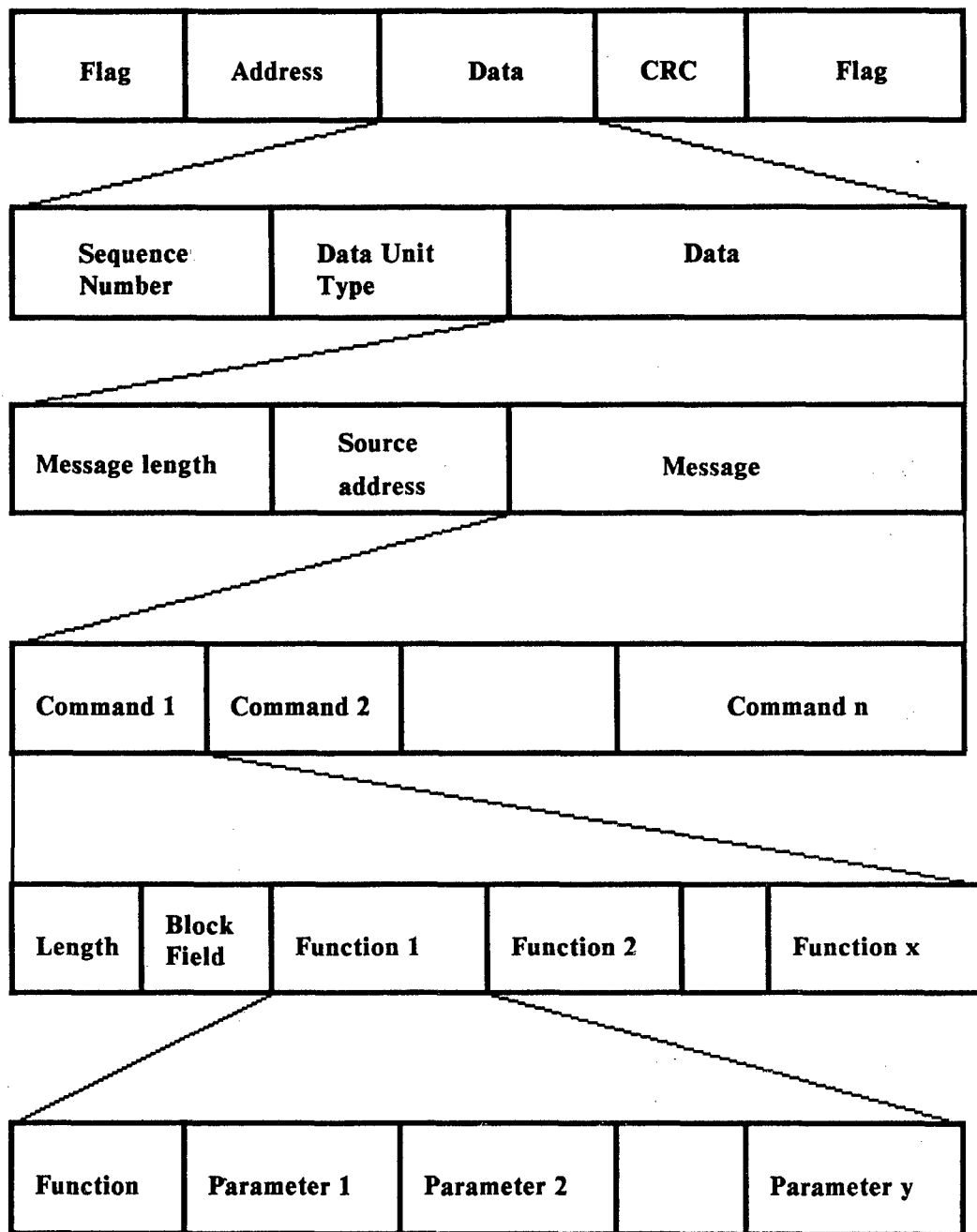
**Figure 5-7.  Complete Data Packet**

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**APPENDIX A**

**CONTROL/STATUS OF MANNED MILITARY VEHICLES**

## MANNED VEHICLE CONTROLS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Accelerator | | | X | X |
| Bilge pumps on/off | X | X | | X |
| Brake | X | X | X | X |
| Defroster control | | | X | |
| Driver's night vision viewer | X | | | |
| Driver's periscope wiper | X | | | |
| Engine accesory | | X | | |
| Engine shutoff | X | | X | |
| Engine starter | X | | X | X |
| Engine starter (cold start) | | X | | X |
| Fire suppression | | X | | |
| Fording control | | | X | |
| Fuel control | | X | | |
| Fuel tank selector | X | | | |
| Garage toggle | | | | X |
| Gear selector | X | X | X | X |
| Hazard warning light | | | X | X |
| High/low ratio selector | | | | X |
| Horn | | X | X | |
| Infrared lenses | X | | | |

## MANNED VEHICLE CONTROLS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Intercom | X | X | | |
| Light selector | X | X | X | X |
| Master power | X | X | | |
| NBC system on/off | | X | | X |
| Panel lights control | X | X | X | X |
| Parking brake release | X | | X | |
| Parking brake set | X | X | X | |
| Periscope adjustment | X | | | |
| Periscope washer pump | X | | | |
| Pivot | X | X | | X |
| Road/water toggle | | | | X |
| Service brake | X | X | | |
| Smoke screen generator | X | X | | |
| Splash guard up/down | | | | X |
| Steering | X | X | X | X |
| Steering wheel lock cable | | | X | |
| Tactical idle | X | | | |
| Throttle control | X | X | X | |
| Transfer case | | | X | |
| Transmission on/off | | | | X |

## MANNED VEHICLE CONTROLS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Turn indicator | | X | X | X |
| Water barrier release | | X | | |
| Windshield washer/wiper | | | X | |

# MANNED VEHICLE STATUS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Air cleaner clogged warning | | X | X | |
| Alternator temperature high | | | | X |
| Back door open | | | | X |
| Battery charge low | X | | | |
| Bilge pump (fwd,rear) | X | X | | X |
| Brake master cyl fluid level low | | | X | |
| Brake worn | X | | | |
| Cable disconnected | X | | | |
| Circuit breaker open | X | | | |
| Cold start indicator | | X | X | |
| Coolant high temp warning | | X | | X |
| Coolant low level warning | | X | | X |
| Engine started | X | | | |
| Engine abort | X | | | |
| Engine accessory indicator | | X | | |
| Engine coolant temp gauge | X | X | X | |
| Engine hour meter | X | | | X |
| Engine oil filter clogged | X | | | |
| Engine oil low | | | | X |
| Engine oil pressure gauge | X | X | X | |

## MANNED VEHICLE STATUS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Engine oil pressure warning | X | X | X | X |
| Engine oil temperature high | X | | | X |
| Exhaust temperature | | | | X |
| Fire detector sensor | X | | | |
| Fire ext bottle pres gauge | X | | | |
| Fire supp discharge indicator | X | X | | |
| Fire supp manual indicator | | X | | |
| Fuel (F,1/2,1/4,E) | | | | X |
| Fuel control faulty | X | | | |
| Fuel filter clogged warning | X | X | | |
| Fuel gauge | X | X | X | |
| Fuel level low | X | | | |
| Full pivot | | | | X |
| Gas over temperature | X | | | |
| Headlights high beam | X | X | X | X |
| Headlights low beam | X | | | X |
| Heater control | | | X | |
| Heater fan | | | X | |
| Hydraulic system malfunction | X | | | |
| Master caution | X | | | |

## MANNED VEHICLE STATUS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Master power indicator | X | X | | |
| Master warning | X | | | |
| NBC filter clogged | X | | | |
| NBC on | | | | X |
| NBC overheated | X | | | |
| NBC overpressure | X | | | |
| NBC system indicator | | X | | X |
| Night periscope | X | | | |
| Odometer | X | X | X | X |
| Parking brake sys hyd pres gauge | X | | X | |
| Parking lights on | | | | X |
| Parking/service brake on | X | | | |
| Ramp unlock indicator | | X | | |
| Rear left fuel pump bad | X | | | |
| Rear right fuel pump bad | X | | | |
| Road mode | | | | X |
| STE/ICE diagnostic connector | | | X | |
| Slope indicator | | X | | |
| Smoke screen generator on | X | X | | |
| Speedometer | X | X | X | X |

## MANNED VEHICLE STATUS

| Description of function | M1 Abrams (heavy) | M2/M3 Bradley (med) | HMMWV (light) | Cobra (elec) |
|---|---|---|---|---|
| Tachometer | X | | | X |
| Transmission damage-inspect | X | | | |
| Transmission gear selected | X | X | X | X |
| Transmission off | | | | X |
| Transmission oil filter clogged | X | | | |
| Transmission oil low | X | | | |
| Transmission oil pressure warning | X | X | | |
| Transmission oil temp warning | X | X | | |
| Trip odometer | | | | X |
| Turn indicator lights | X | X | X | X |
| Turret power indicator | | X | | |
| Turret seal pressure gauge | X | | | |
| Voltage gauge | X | X | X | |
| Water mode | | | | X |

# APPENDIX B


# CONTROL/STATUS REQUIRED FOR ROBOTIC VEHICLE SYSTEMS

Controls Required for

Robotic Vehicle Systems

1. Power plant
2. Brakes
3. Steering
4. Transmission
5. Suspension
6. Fording
7. Mobility
8. Fuel

9. Turret
10. Interior
11. Lights
12. Electro-optic Sensors
13. Condition Sensors
14. Communications
15. Inertial Navigation System
16. Mission module

# REQUIRED CONTROLS

1. Power plant

    Start

    Cold start

    Kill

    Throttle

    Idle set

    Tactical idle

    Fuel delivery

    Cruise control (CC)

        CC Set
        CC Resume
        CC Accelerate
        CC Decelerate
        CC Coast

    Electric current *

2. Brakes

    Brake

    Parking brake set/unset

    Service brake set/unset

3. Steering

    Steer

    Radius of turn

    Heading

    Directional movement

* For battery power plant

REQUIRED CONTROLS

4. Transmission

    Automatic gear select

        Park
        Reverse
        Neutral
        Drive
        Drive, L
        Pivot
        Tow

    Manual Gear select

    Transfer case

        High
        Low
        Neutral

    Wheel drive

5. Suspension

    Air shock height

    Hydroneumatic suspension level control

6. Fording

    Road/water propulsion

    Splash guard up/down

    Water barrier release level

    Exhaust pipe rise

7. Mobility

    Emergency stop

    Velocity

    Move to grid coordinates

    Pivot

    CARD mode

    Autonomous road following mode

## REQUIRED CONTROLS

8.  Fuel

    Fuel tank selector

    Fuel filler lock/unlock

    Fuel filler open/close

9.  Turret

    Power

    Enable (turret travel lock)

    Slew

    Elevation

10. Interior

    Defroster

    Heater

    Air Conditioner

    Temperature setting

    NBC system On/Off

    Bilge pumps, front

    Bilge pumps, rear

    Fire supression

    Horn

    Vent open/close

    Vent fan

    Wipers

    Heated glass

    Doors lock/unlock

    Windows up/down

REQUIRED CONTROLS

11.   Lights

      Head lights

          High beam
          Low Beam

      Parking lights

      Turn indicator

          Left
          Right

      Hazard lights

      Blackout lights

      Interior lights

      Exterior flood lights

      Exterior spot light

      Fog lights

      Back-up lights

12.   Electro-optic Sensors

      Sensor switch

          Video
          Radar
          IR Thermal imaging system
          Image intensifier
          Laser ranger

      Video camera selector

          Forward
          Stereo
          Rear

      Sensor control

          Azimuth
          Elevation
          Tilt
          Scan rate
          Sector size

REQUIRED CONTROLS

12.  Electro-optic Sensors (cont)

Sensor control

B & W/Color
Contrast
Iris F/B switch
Shutter speed
Zoom
Focus
Home
Wipers
De-icer
Convergence
Hot/white
Logic select
Field of view

13.  Condition sensors

Radar detector

Magnetic field detector

Motion detector

Frequency detector

Light detector

Sonic detector

NBC detector

Noise detector

Rain detector

Snow detector

14.  Communications

System choice

RF
Fiber optic
Microwave
Laser

REQUIRED CONTROLS

14. Communications (cont)

    Radio options

        Frequency select
        AJ techniques
        Transmitting power

    Fiber optic options

    Antenna control

        Elevation
        Azimuth
        Polarization
        Auto-track

15. Inertial navigation system

    Initialize

    Reset

16. Mission module

    Reconnaissance module

    Mine field breacher

    Weapons package

    CARD module

    Jamming device

    Smoke generator

    Others to be determined

## Status Required for
## Robotic Vehicle Systems

| | | | |
|---|---|---|---|
| 1. | Power plant | 10. | Interior |
| 2. | Brakes | 11. | Lights |
| 3. | Steering | 12. | Electro-optic Sensors |
| 4. | Transmission | 13. | Condition Sensors |
| 5. | Suspension | 14. | Communications |
| 6. | Fording | 15. | Inertial Navigation Data |
| 7. | Mobility | 16. | Mission modules |
| 8. | Fuel | 17. | Circuit breaker faults |
| 9. | Turret | 18. | Exterior |

REQUIRED STATUS

1.  Power plant

    Running/started

    Tachometer

    Coolant

        Temperature gauge
        Low level
        High temperature

    Oil

        Pressure gauge
        Pressure low
        Level low
        Temperature high

    Alternator

        Temperature high
        Not functioning

    Cold start indicator

    Exhaust temp high

    Battery charge low

    Voltage gauge

    Air cleaner clogged

    Oil filter clogged

    Fuel filter clogged

    Fuel pump bad

    Fuel control faulty

    Hour meter

    Throttle feedback

    Microphone in engine compartment On/Off

REQUIRED STATUS

2.  Brakes

        Brake feedback

        Brakes worn

        Master cylinder fluid level low

        Brake line pressure gauge

        Low brake air

        Brakes nonfunctional

        Parking brake

                On/Off
                Hydraulic pressure gauge

3.  Steering

        Steering feedback

4.  Transmission

        Automatic transmission gear selected

                Park
                Reverse
                Neutral
                Drive
                Drive, L
                Drive, H
                Pivot
                Tow

        Manual transmission gear selected

        Transfer case
                High
                Low
                Neutral

        Wheel drive

        Transmission fluid

        Filter clogged

        Pressure warning

B-12

REQUIRED STATUS

4. Transmission (cont)

   Temperature warning

   Level low

   Damaged

   Shift gear indicator

5. Suspension

   Air shock height

   Hydroneumatic suspension level

6. Fording

   River depth

   River current speed

   Road/water propulsion

7. Mobility

8. Fuel

   Fuel gauge

   Fuel low

   Fuel temperature high

   Fuel filler cover on/off, lock/unlock

   Fuel leak alarm

   Instantaneous MPG

   Battery powerpack charge level

9. Turret

   Power

   Seal pressure gauge

REQUIRED STATUS

10. Interior

Vehicle interior temperature

NBC system

    On/Off
    Filter clogged
    System overheated
    System overpressure

Bilge pump, front

Bilge pump, rear

Fire supression

    Detector
    Discharge indicator
    Extinguisher bottle pressure gauge

Wipers on/off

Door lock/unlock

Windows up/down

Vent open/close

Vent fan on/off

Cabin pressure

Moisture detector alarm/level meter

Door/hatch ajar

Heater on/off

Air conditioner on/off

Absorbed power

11. Lights

Head lights

    High beam
    Low beam

Parking lights

11. Lights (cont)

> Turn indicators
>
> Hazard lights
>
> Blackout lights
>
> Interior lights
>
> Exterior flood lights
>
> Exterior spot lights
>
> Fog lights
>
> Back-up lights
>
> Engine compartment lights
>
> Bulb burned out

12. Electro-optic sensors

> Sensor switch
>
>> Video
>> Radar
>> IR Thermal imaging system
>> Image intensifier
>> Laser ranger
>
> Video camera selector
>
>> Forward
>> Stereo
>> Rear
>
> Sensor control
>
>> Scan rate
>> Sector size
>> B & W/Color
>> Iris F/B switch
>> Shutter speed
>> Wipers
>> Convergence
>> Hot/white
>> Logic select
>> Field of view

# REQUIRED STATUS

13. Condition sensors

Radar detected

Magnetic field detected

Motion detected

Frequency detected

Light detected

Sound detected

NBC detected

Noise detected

Rain detected

Snow detected

14. Communciations

System choice

RF
Fiber optics
Microwave

Radio options

Frequency selected
AJ technique
Transmitting power

F.O. status

Cable used
Cable left
Cable cut

Antenna

Polarization
Auto-track on

15. Inertial navigation system data

     Heading

     Altitude

     Roll

     Pitch

     Yaw

     Roll limit warning

     Pitch limit warning

     Slope indicator

     Speedometer

     Odometer

     Trip odometer

     Doppler speed

     Wheel count speed

     UTM coordinates

     Latitude

     Longitude

16. Mission modules

     Reconnaissance module

     Mine field breacher

     Weapons package

     CARD module

     Jamming device

     Smoke generator

     Others to be determined

17. Circuit Breaker Faults

> Master
>
> Light
>
> Ignition
>
> Brake boost

18. Exterior

> Vehicle hit
>
> Track off
>
> Exterior temperature
>
> Audio sensors (microphone)
>
> Tire flat
>
> Intrusion detection system

# APPENDIX C

# CONTROL COMMAND CODING

## RCC TO RV CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Power plant | 01 | | |
| Start | | 01 | |
| Kill | | 02 | |
| Throttle | | 03 | |
| Cold start | | 04 | PI |
| Tactical idle on | | 05 | |
| Tactical idle off | | 06 | |
| Idle set | | 07 | PI |
| Fuel turn on | | 09 | |
| Fuel shut off | | 0A | |
| Cruise control set | | 0B | |
| Cruise control resume | | 0C | |
| Cruise control accelerate | | 0D | |
| Cruise control decelerate | | 0E | |
| Cruise control coast | | 0F | |
| Electric current flow | | 10 | PI |
| | | | |
| Brakes | 02 | | |
| Brake | | 01 | PI |
| Parking brake set | | 02 | |
| Parking brake unset | | 03 | |
| Service brake set | | 04 | |
| Service brake unset | | 05 | |
| | | | |
| Steering | 03 | | |
| Steer | | 01 | PI |
| Radius of turn | | 02 | N |
| Heading | | 03 | N |
| Directional movement | | 04 | N |
| | | | |
| Automatic transmission | 04 | | S |
| Park | | | 01 |
| Reverse | | | 02 |
| Neutral | | | 03 |
| Drive | | | 04 |
| Drive, L | | | 05 |
| Drive, H | | | 06 |
| Pivot | | | 07 |
| Tow | | | 08 |
| | | | |
| Manual transmission | 05 | | S |
| Reverse | | | 00 |
| First | | | 01 |
| Second | | | 02 |
| Third | | | 03 |

## CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Fourth | | | 04 |
| Fifth | | | 05 |
| **Transfer case** | 06 | | S |
| **Wheel drive** | 07 | | S |
| **Suspension** | 08 | | |
| Air shock height | | 01 | PI |
| Suspension height | | 02 | PI |
| **Fording** | 09 | | |
| Road propulsion | | 01 | |
| Water propulsion | | 02 | |
| Splash guard up | | 03 | |
| Splash guard down | | 04 | |
| Water barrier set | | 05 | |
| Water barrier release | | 06 | |
| Exhaust pipe rise | | 07 | |
| Exhaust pipe lower | | 08 | |
| **Mobility** | 0A | | |
| Emergency stop | | 01 | |
| Velocity | | 02 | N |
| Grid coordinates | | 03 | N |
| Pivot left | | 04 | PI |
| Pivot right | | 05 | PI |
| CARD mode, enter | | 11 | |
| CARD mode, exit | | 12 | |
| CARD command identifier | | 13 | |
| Autonomous road following, on | | 15 | |
| Autonomous road following, off | | 16 | |
| **Fuel** | 0B | | |
| Fuel tank A | | 01 | |
| Fuel tank B | | 02 | |
| Fuel filler lock | | 03 | |
| Fuel filler unlock | | 04 | |
| Fuel filler open | | 05 | |
| Fuel filler close | | 06 | |
| **Turret** | 0C | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Enable | | 03 | |
| Disable | | 04 | |
| Slew | | 05 | PI |

## CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Elevation | | 06 | PI |
| **Interior** | 0D | | |
| Defroster on | | 01 | |
| Defroster off | | 02 | |
| Heater on | | 03 | |
| Heater off | | 04 | |
| Air conditioner on | | 05 | |
| Air conditioner off | | 06 | |
| NBC system on | | 07 | |
| NBC system off | | 08 | |
| Bilge pumps, front, on | | 09 | |
| Bilge pumps, front, off | | 0A | |
| Bilge pumps, rear, on | | 0B | |
| Bilge pumps, rear, off | | 0C | |
| Fire suppression on | | 0D | |
| Fire suppression off | | 0E | |
| Vent open | | 11 | |
| Vent close | | 12 | |
| Vent fan on | | 13 | |
| Vent fan off | | 14 | |
| Wipers on | | 15 | |
| Wipers off | | 16 | |
| Heated glass on | | 17 | |
| Heated glass off | | 18 | |
| Doors lock | | 19 | |
| Doors unlock | | 1A | |
| Temperature setting | | 20 | N |
| Horn | | 21 | |
| Windows up/down | | 22 | PI |
| **Lights** | 0E | | |
| Head lights on | | 01 | |
| Head lights off | | 02 | |
| High beam on | | 03 | |
| High beam off | | 04 | |
| Parking lights on | | 05 | |
| Parking lights off | | 06 | |
| Right turn indicator | | 07 | |
| Left turn indicator | | 08 | |
| Hazard lights on | | 09 | |
| Hazard lights off | | 0A | |
| Blackout lights on | | 0B | |
| Blackout lights off | | 0C | |
| Interior lights | | 0D | |
| Fog lights on | | 0E | |
| Fog lights off | | 0F | |

# CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Back-up lights on | | 10 | |
| Back-up lights off | | 11 | |
| Exterior flood lights | | 12 | |
| Spot light on | | 13 | |
| Spot light off | | 14 | |
| Spot light elevation | | 15 | PI |
| Spot light azimuth | | 16 | PI |
| Spot light tilt | | 17 | PI |
| | | | |
| **Electro-optic Sensor** | | | |
| **Image Transmit Select** | 10 | | S |
| Video, forward, transmit | | | 01 |
| Video, forward, do not transmit | | | 02 |
| Video, Stereo, transmit | | | 03 |
| Video, Stereo, do not transmit | | | 04 |
| Video, left peripheral, transmit | | | 05 |
| Video, left peripheral, do not transmit | | | 06 |
| Video, right peripheral, transmit | | | 07 |
| Video, right peripheral, do not transmit | | | 08 |
| Video, rear, transmit | | | 09 |
| Video, rear, do not transmit | | | 0A |
| Video, reconnaissance, transmit | | | 0B |
| Video, reconnaissance, do not transmit | | | 0C |
| Driver's thermal viewer (DTV), transmit | | | 0D |
| Driver's thermal viewer (DTV), do not transmit | | | 0E |
| Forward looking infrared (FLIR), transmit | | | 0F |
| Forward looking infrared (FLIR), do not transmit | | | 10 |
| Radar, transmit | | | 11 |
| Radar, do not transmit | | | 12 |
| Laser, transmit | | | 13 |
| Laser, do not transmit | | | 14 |
| | | | |
| **Video, forward** | 11 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |
| De-icer off | | 09 | |
| Wipers on | | 0A | |
| Wipers off | | 0B | |
| Contrast | | 0C | PI |
| Iris adjust | | 0D | PI |
| Shutter speed | | 0E | N |

# CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Zoom | | ØF | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| **Video, Stereo** | 12 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Slew | | Ø3 | PI |
| Elevation | | Ø4 | PI |
| Tilt | | Ø5 | PI |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| De-icer on | | Ø8 | |
| De-icer off | | Ø9 | |
| Wipers on | | ØA | |
| Wipers off | | ØB | |
| Contrast | | ØC | PI |
| Iris adjust | | ØD | PI |
| Shutter speed | | ØE | N |
| Zoom | | ØF | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| **Video, left peripheral** | 13 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Slew | | Ø3 | PI |
| Elevation | | Ø4 | PI |
| Tilt | | Ø5 | PI |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| De-icer on | | Ø8 | |
| De-icer off | | Ø9 | |
| Wipers on | | ØA | |
| Wipers off | | ØB | |
| Contrast | | ØC | PI |
| Iris adjust | | ØD | PI |
| Shutter speed | | ØE | N |
| Zoom | | ØF | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| **Video, right peripheral** | 14 | | |
| Power on | | Ø1 | |

# CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |
| De-icer off | | 09 | |
| Wipers on | | 0A | |
| Wipers off | | 0B | |
| Contrast | | 0C | PI |
| Iris adjust | | 0D | PI |
| Shutter speed | | 0E | N |
| Zoom | | 0F | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| | | | |
| **Video, rear** | 15 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |
| De-icer off | | 09 | |
| Wipers on | | 0A | |
| Wipers off | | 0B | |
| Contrast | | 0C | PI |
| Iris adjust | | 0D | PI |
| Shutter speed | | 0E | N |
| Zoom | | 0F | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| | | | |
| **Video, reconnaissance** | 16 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |

# CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| De-icer off | | 09 | |
| Wipers on | | 0A | |
| Wipers off | | 0B | |
| Contrast | | 0C | PI |
| Iris adjust | | 0D | PI |
| Shutter speed | | 0E | N |
| Zoom | | 0F | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| | | | |
| **Driver's thermal viewer (DTV) 17** | | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |
| De-icer off | | 09 | |
| Wipers on | | 0A | |
| Wipers off | | 0B | |
| Contrast | | 0C | PI |
| Iris adjust | | 0D | PI |
| Shutter speed | | 0E | N |
| Zoom | | 0F | PI |
| Focus | | 10 | PI |
| Home | | 11 | |
| Convergence | | 12 | PI |
| Stand by | | 13 | |
| Thermal hot | | 14 | |
| Thermal cold | | 15 | |
| | | | |
| **Forward looking infrared (FLIR) 18** | | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Slew | | 03 | PI |
| Elevation | | 04 | PI |
| Tilt | | 05 | PI |
| Scan rate | | 06 | N |
| Sector size | | 07 | N |
| De-icer on | | 08 | |
| De-icer off | | 09 | |
| Contrast | | 0C | PI |
| Zoom | | 0F | PI |
| Focus | | 10 | PI |

# CONTROL COMMAND CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Home | | 11 | |
| Flir thermal level | | 13 | PI |
| Flir thermal gain | | 14 | PI |
| Flir focus | | 15 | PI |
| Flir contrast | | 16 | PI |
| **Conditions Sensors** | 20 | | |
| Radar detector on | | 01 | |
| Radar detector off | | 02 | |
| Magnetic field detector on | | 03 | |
| Magnetic field detector off | | 04 | |
| Motion detector on | | 05 | |
| Motion detector off | | 06 | |
| Frequency detector on | | 07 | |
| Frequency detector off | | 08 | |
| Light detector on | | 09 | |
| Light detector off | | 0A | |
| Sonic detector on | | 0B | |
| Sonic detector off | | 0C | |
| NBC detector on | | 0D | |
| NBC detector off | | 0E | |
| Noise detector on | | 0F | |
| Noise detector off | | 10 | |
| Rain detector on | | 11 | |
| Rain detector off | | 12 | |
| Snow detector on | | 13 | |
| Snow detector off | | 14 | |
| **VHF radio** | 21 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Frequency select | | 03 | N |
| Radio transmitting power | | 04 | PI |
| Antenna azimuth | | 05 | PI |
| Antenna elevation | | 06 | PI |
| Antenna polarization | | 07 | S |
| Antenna auto-track on | | 08 | |
| Antenna auto-track off | | 09 | |
| **Microwave radio** | 22 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Frequency select | | 03 | N |
| Radio transmitting power | | 04 | PI |
| Antenna azimuth | | 05 | PI |
| Antenna elevation | | 06 | PI |
| Antenna polarization | | 07 | S |

## CONTROL COMMAND CODING

| Function/status<br>Description | Block<br>Field | Function<br>Field | Parameter<br>Field |
|---|---|---|---|
| Antenna auto-track on | | 08 | |
| Antenna auto-track off | | 09 | |
| Fiber optic link | 23 | | |
| Laser link | 24 | | |
| Inertial navigation system | 30 | | |
| Initialize | | 01 | TBD |
| Reset | | 02 | |
| Mission module platform | 40 | | |

**APPENDIX D**

**STATUS INFORMATION CODING**

# RV TO RCC STATUS INFORMATION CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| **Power plant** | 81 | | |
| Engine running | | 01 | |
| Engine not running | | 02 | |
| Tachometer | | 03 | N |
| Coolant temperature gauge | | 04 | N |
| Coolant level low | | 05 | |
| Coolant temperature high | | 06 | |
| Oil pressure gauge | | 07 | N |
| Oil pressure low | | 08 | |
| Oil level low | | 09 | |
| Oil temperature high | | 0A | |
| Oil filter clogged | | 0B | |
| Alternator temperature high | | 0C | |
| Alternator not functioning | | 0D | |
| Cold start indicator | | 0E | |
| Exhaust temperature high | | 0F | |
| Battery charge low | | 10 | |
| Voltage gauge | | 11 | N |
| Air cleaner clogged | | 12 | |
| Fuel filter clogged | | 13 | |
| Fuel pump bad | | 14 | |
| Hour meter | | 15 | N |
| Throttle feedback | | 16 | PI |
| Engine microphone on | | 17 | |
| Engine microphone off | | 18 | |
| **Brakes** | 82 | | |
| Brake | | 01 | PI |
| Brakes worn | | 02 | |
| Master cylinder fluid level low | | 03 | |
| Brake line pressure gauge | | 04 | N |
| Low brake air | | 05 | |
| Brakes nonfunctional | | 06 | |
| Parking brake set | | 07 | |
| Parking brake hydraulic pressure gauge | | 08 | N |
| **Steering** | 83 | | |
| Steering feedback | | 01 | PI |
| **Automatic transmission gear** | 84 | | S |
| Park | | | 01 |
| Reverse | | | 02 |
| Neutral | | | 03 |

# RV TO RCC STATUS INFORMATION CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Drive, L | | | 05 |
| Drive, H | | | 06 |
| Pivot | | | 07 |
| Tow | | | 08 |
| Fluid filter clogged | | | 10 |
| Fluid pressure low | | | 11 |
| Fluid temperature high | | | 12 |
| Fluid level low | | | 13 |
| Transmission damaged | | | 14 |
| | | | |
| **Manual transmission gear** | 85 | | S |
| Reverse | | | 00 |
| First | | | 01 |
| Second | | | 02 |
| Third | | | 03 |
| Fourth | | | 04 |
| Fifth | | | 05 |
| Fluid filter clogged | | | 10 |
| Fluid pressure low | | | 11 |
| Fluid temperature high | | | 12 |
| Fluid level low | | | 13 |
| Transmission damaged | | | 14 |
| Shift gear indicator | | | 1A |
| | | | |
| **Transfer case** | 86 | | S |
| | | | |
| **Wheel drive** | 87 | | S |
| | | | |
| **Suspension** | 88 | | |
| Air shock height | | 01 | N |
| Hydronuematic suspension level | | 02 | N |
| | | | |
| **Fording** | 89 | | |
| River depth | | 01 | N |
| River current speed | | 02 | N |
| Road propulsion | | 03 | |
| Water propulsion | | 04 | |
| | | | |
| **Mobility** | 8A | | |
| In CARD mode | | 11 | |
| In autonomous mode | | 15 | |
| | | | |
| **Fuel** | 8B | | |
| | | | |
| Fuel gauge | | 01 | N |
| Fuel low | | 02 | |

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Fuel temperature high | | 03 | |
| Fuel filler cover off | | 04 | |
| Fuel filler cover unlocked | | 05 | |
| Fuel leak | | 06 | |
| Instantaneous MPG | | 07 | N |
| Battery power pack charge level | | 08 | N |
| **Turret** | 8C | | |
| Power | | 01 | |
| Seal pressure gauge | | 02 | N |
| **Interior** | 8D | | |
| Temperature | | 01 | N |
| NBC system on | | 02 | |
| NBC filter clogged | | 03 | |
| NBC system overheated | | 04 | |
| NBC system over pressure | | 05 | |
| Front bilge pump on | | 06 | |
| Rear bilge pump on | | 07 | |
| Fire detected | | 08 | |
| Fire supression discharged | | 09 | |
| Fire extinguisher bottle pressure gauge | | 0A | N |
| Wipers on | | 0B | |
| Doors unlocked | | 0C | |
| Windows down | | 0D | |
| Vent open | | 0E | |
| Vent fan on | | 0F | |
| Cabin pressure | | 10 | N |
| Moisture level high | | 11 | |
| Door/hatch ajar | | 12 | |
| Heater on | | 13 | |
| Air conditioner on | | 14 | |
| Absorbed power | | 15 | N |
| **Lights** | 8E | | |
| Head lights low beam | | 01 | |
| Head lights high beam | | 02 | |
| Parking lights | | 03 | |
| Left turn indicator | | 04 | |
| Right turn indicator | | 05 | |
| Hazard lights | | 06 | |
| Blackout lights | | 07 | |
| Interior light, front | | 08 | |
| Interior light, middle | | 09 | |
| Interior light, back | | 0A | |

# RV TO RCC STATUS INFORMATION CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Exterior flood light | | ØB | |
| Exterior spot light | | ØC | |
| Fog lights | | ØD | |
| Back-up lights | | ØE | |
| Engine compartment light | | ØF | |
| Bulb(s) burned out | | 10 | S |
| | | | |
| **Electro-optic Sensor** | | | |
|    **Image Transmit Select** | 90 | | S |
| Video, forward, transmitting | | | Ø1 |
| Video, forward, not transmitting | | | Ø2 |
| Video, Stereo, transmitting | | | Ø3 |
| Video, Stereo, not transmitting | | | Ø4 |
| Video, left peripheral, transmitting | | | Ø5 |
| Video, left peripheral, not transmitting | | | Ø6 |
| Video, right peripheral, transmitting | | | Ø7 |
| Video, right peripheral, not transmitting | | | Ø8 |
| Video, rear, transmitting | | | Ø9 |
| Video, rear, not transmitting | | | ØA |
| Video, reconnaissance, transmitting | | | ØB |
| Video, reconnaissance, not transmitting | | | ØC |
| Driver's thermal viewer (DTV), transmitting | | | ØD |
| Driver's thermal viewer (DTV), not transmitting | | | ØE |
| Forward looking infrared (FLIR), transmitting | | | ØF |
| Forward looking infrared (FLIR), not transmitting | | | 10 |
| Radar, transmitting | | | 11 |
| Radar, not transmitting | | | 12 |
| Laser, transmitting | | | 13 |
| Laser, not transmitting | | | 14 |
| | | | |
| **Video, forward** | 91 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Video, Stereo** | 92 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Video, left peripheral** | 93 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Video, right peripheral** | 94 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Video, rear** | 95 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Video, reconnaissance** | 96 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Shutter speed | | ØE | N |
| | | | |
| **Driver's thermal viewer (DTV)** | 97 | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| Stand by | | 1Ø | |
| Thermal hot | | 14 | |
| Thermal cold | | 15 | |
| | | | |
| **Forward looking infrared (FLIR)** | 98 | | |
| | | | |
| Power on | | Ø1 | |
| Power off | | Ø2 | |
| Scan rate | | Ø6 | N |
| Sector size | | Ø7 | N |
| FLIR thermal level | | 13 | PI |
| FLIR thermal gain | | 14 | PI |
| FLIR focus | | 15 | PI |
| FLIR contrast | | 16 | PI |
| | | | |
| **Condition sensors** | AØ | | |
| Radar detected | | Ø1 | |

# RV TO RCC STATUS INFORMATION CODING

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Magnetic field detected | | 02 | |
| Motion detected | | 03 | |
| Frequency detected | | 04 | |
| Light detected | | 05 | |
| Sound detected | | 06 | |
| NBC detected | | 07 | |
| Rain detected | | 08 | |
| Snow detected | | 09 | |
| | | | |
| **VHF radio** | A1 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Frequency select | | 03 | N |
| Radio transmitting power | | 04 | PI |
| Antenna azimuth | | 05 | PI |
| Antenna elevation | | 06 | PI |
| Antenna polarization | | 07 | S |
| Antenna auto-track on | | 08 | |
| Antenna auto-track off | | 09 | |
| | | | |
| **Microwave radio** | A2 | | |
| Power on | | 01 | |
| Power off | | 02 | |
| Frequency select | | 03 | N |
| Radio transmitting power | | 04 | PI |
| Antenna azimuth | | 05 | PI |
| Antenna elevation | | 06 | PI |
| Antenna polarization | | 07 | S |
| Antenna auto-track on | | 08 | |
| Antenna auto-track off | | 09 | |
| | | | |
| **Fiber optic link** | A3 | | |
| Fiber optic cable cut | | 02 | |
| Fiber optic cable left on spool | | 03 | N |
| Fiber optic cable dispensed | | 04 | N |
| | | | |
| **Laser link** | A4 | | |
| | | | |
| **Navigation** | B0 | | |
| Heading | | 01 | N |
| Altitude | | 02 | N |
| Roll | | 03 | N |
| Pitch | | 04 | N |
| Yaw | | 05 | N |
| Roll limit warning | | 06 | |
| Pitch limit warning | | 07 | |
| Slope indicator | | 08 | N |

| Function/status Description | Block Field | Function Field | Parameter Field |
|---|---|---|---|
| Speedometer | | 09 | N |
| Odometer | | 0A | N |
| Trip odometer | | 0B | N |
| Doppler speed | | 0C | N |
| Wheel count speed | | 0D | N |
| UTM coordinates | | 0E | N |
| Latitude | | 0F | N |
| Longitude | | 10 | N |
| **Mission Modules platform** | C0 | | |
| **Circuit Breaker Faults** | D0 | | |
| Master | | 01 | |
| Light | | 02 | |
| Ignition | | 03 | |
| Brake boost | | 04 | |
| **Exterior** | E0 | | |
| Vehicle hit | | 01 | |
| Track off | | 02 | |
| Exterior temperature | | 03 | N |
| Tire flat | | 04 | |
| Intrusion detection | | 05 | |

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